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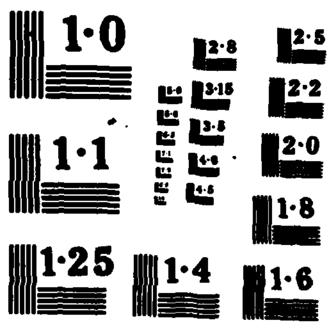
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RECENT EXPERIENCE IN THE RAE 5 METRE WIND TUNNEL OF A CHINA CLAY METHOD FOR INDICATING BOUNDARY LAYER TRANSITION

by

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SUMMARY

Details of a visual method for indicating boundary layer transition are given, with particular reference to tests at high Reynolds number in the RAE 5 metre pressurised low-speed wind tunnel on a slender-body model. The method is compared with other techniques on the basis of ease of use and quality of the indication.

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1 INTRODUCTION

The prime role of the RAE 5 metre pressurised low-speed wind tunnel[1] is the investigation of Reynolds and Mach number effects at low speeds on a variety of aircraft and weapon configurations. One of the more important consequences of varying the Reynolds number of a flow is how this variation affects the type and position of transition from laminar to turbulent flow in the boundary layer.

For example, in the course of a series of wind tunnel tests on a 20° cone/cylinder slender body, the position of the transition was investigated, as this is believed to influence strongly the subsequent development of the separated flow over this type of configuration. This Memorandum gives details of the method used to indicate transition.

2 SELECTION OF METHOD

Since the model did not have any pressure tappings in its surface, the razor-blade technique[2,3] of indicating transition by change in skin friction could not be used; it would not in any case have given a sufficiently 'global' and detailed indication of the transition position. Similar considerations ruled out the use of hot-film gauges[4], and the 5 metre wind tunnel does not possess suitable equipment for boundary-layer traverse techniques[3]. A flow visualisation method was therefore required.

The technique most commonly used at RAE in recent years is that involving the sublimation of a layer of naptha crystals dissolved in petroleum ether, as reported by Pringle and Main-Smith[5] and used recently by Holmes and Obara[6]. This method was tried, but discarded for the following reasons:

(i) The napthalene is sprayed on to the surface in an attempt to achieve a uniform coating. This is an unpleasant task requiring the wearing of a respirator and goggles by the operator.

(ii) The napthalene has to be cleaned off after each run to avoid the build-up of thick deposits. This is very time-consuming.

(iii) No definite indication of transition was obtained on the slender-body model, possibly due to the difficulty of obtaining an even coating on a surface with high curvature.

Attention was then turned to the China Clay Method. This was reported by Richards and Burstall[7] as a new technique in 1945, and is often mentioned in text books, but seems to have been neglected in recent years. The method is based on the differential rate of evaporation, beneath laminar and turbulent boundary layers, of a liquid absorbed on a solid spread on the surface. The liquid is chosen to have a similar refractive index to the solid so that the mixture appears to be transparent until evaporation has taken place, when the colour of the solid becomes visible.

3 DETAILS OF THE CHINA CLAY METHOD

The solid layer ~~described in section~~ consists of china clay powder mixture with certain chemicals to form a lacquer, which is sprayed on to the surface. When dry, this forms a semi-permanent white absorbent film. A suitable liquid sprayed on to this film is absorbed by it, causing it to become transparent. (to back cover)

Richards and Burstall[7] give three alternative formulations for the lacquer, which are broadly based on a cellulose dope. In the recent experiments in the 5 metre tunnel, two of these were discarded, the first because it used dissolved celluloid which is now virtually unobtainable in pure form, and the second because it used an old resin whose modern equivalent was difficult to identify. The third alternative was the one eventually used successfully. This consisted of Frigilene* (a form of dope), diluted with butyl acetate, butyl alcohol and xylene, to which was added the china clay powder. The quantities used were those specified in Ref 7, *ie*

Frigilene	100 ml
Butyl acetate	100 ml
Butyl alcohol	100 ml
Xylene	50 ml
China clay ('Speswhite' or 'Supreme')*	100 gm .

The original report[7] specified that the mixture should be shaken and allowed to stand until 10% of the solid has separated out, before the suspension is poured off and used as the spray mixture. In practice, it was difficult to estimate when this had taken place, and so the mixture was allowed to stand for 10-15 minutes before use.

When the mixture is sprayed on to the surface, as fine a spray as possible is used and the spray gun is held at such a distance that the surface is just wetted. The coating should be as even as possible and any large particles adhering to the surface should be carefully removed with very fine emery paper. The resulting coating is fairly durable unless scuffed and appears to be capable of lasting for several test sessions if handled carefully. However, on completing the tests, the china clay may be removed easily from the model by wiping the surface with methylated spirits.

As the china clay layer itself may influence the boundary layer development, the surface roughness of the model was measured with and without the china clay present. The former gave a maximum roughness height of about 0.012 mm while the latter gave 0.006 mm. An assessment of the significance of this degree of roughness as regards transition is not attempted here; this complex subject is discussed by Thwaites[8], Houghton and Boswell[9] and Batt and Legner[10], amongst others.

A number of liquids are listed in Ref 7 as being suitable for absorption on the china clay, but only one has been tried in this instance. This was methyl salicylate ('oil of wintergreen'), which proved to be very satisfactory. It is quickly absorbed by the china clay provided the spray is again kept as even as possible, and the minimum amount of fluid is used, to avoid runs. Although the vapour is not harmful, some respiratory protection is advisable while spraying.

Methyl salicylate evaporates very slowly under still-air conditions to the extent that evaporation is negligible until air is blown over the surface. This means that there is ample time for closing the tunnel, bringing the pressure up to the desired level,

* Frigilene is used within RAE as a protective coating for metal surfaces. The china clay was obtained from ECC International, St. Austell, Cornwall. The other chemicals may be readily obtained from various suppliers.

setting the model at the required angle of incidence and running the tunnel up to the required speed. Sufficient evaporation of the fluid to produce the transition indication takes 1 to 5 minutes depending on wind speed and total pressure. Repeat runs can be easily made by spraying on more liquid - there is no need to clean the model between runs. As the rate of evaporation is greatly reduced when the fan is stopped, there is plenty of time for depressurising the working section and taking photographs of the transition pattern.

4 DESCRIPTION OF TRANSITION PATTERN

The mechanism of the flow visualisation is that in regions of high skin friction the evaporation rate of the fluid is higher than in regions of low skin friction, making the white of the china clay visible. The details of this process have been analysed by Owen and Ormerod[11]. Five different interpretations of the observed pattern are possible:

(i) Laminar boundary layer near leading edge of aerofoil or body; here the boundary layer is thin with high shear near the surface. This results in high skin friction and hence a high evaporation rate which produces a white region.

(ii) Laminar boundary layer away from leading edge; here the boundary layer shear is much lower and hence the skin friction is also low which produces a low rate of evaporation and the coating stays clear.

(iii) Turbulent boundary layer; here the shear in the laminar sub-layer is very high, producing high skin friction and a high evaporation rate giving a white region.

(iv) Turbulent boundary layer just prior to separation; due to rapid thickening of the boundary layer in this region, skin friction again becomes low and a clear region results.

(v) Separated flow. In general, this can only be identified by reference to the transition pattern as a whole as it could either produce a clear region such as under a 'dead-air' region (or closed separation), or a white region such as may result under a vortex (open separation).

It may be useful to place a small excrescence, such as a piece of plasticene, on the surface. This can be helpful in the interpretation of the flow pattern by producing a transition 'wedge' in a laminar region and thus differentiating between states (ii) and (iv).

5 RESULTS

Fig 1a&b shows photographs of results obtained with the china clay method on the conical nose of a slender-body model. The cone had a semi-apex angle (δ) of 10° and was 1.04 metre long, and the test Reynolds number was 3×10^6, based on the body diameter. The figures show the results obtained at angles of incidence (α) of 20° and 30° respectively. The results from the photographs are shown diagrammatically in Fig 2, which shows that all the states (i) to (iv) referred to in section 4 can be identified with confidence.

6 CONCLUSION

The China Clay Method has been used in the RAE 5 metre wind tunnel for indicating boundary layer transition on a slender-body model. The technique has been found to be fairly easy to prepare, very convenient to use, and gives a clear indication of the various boundary layer states.

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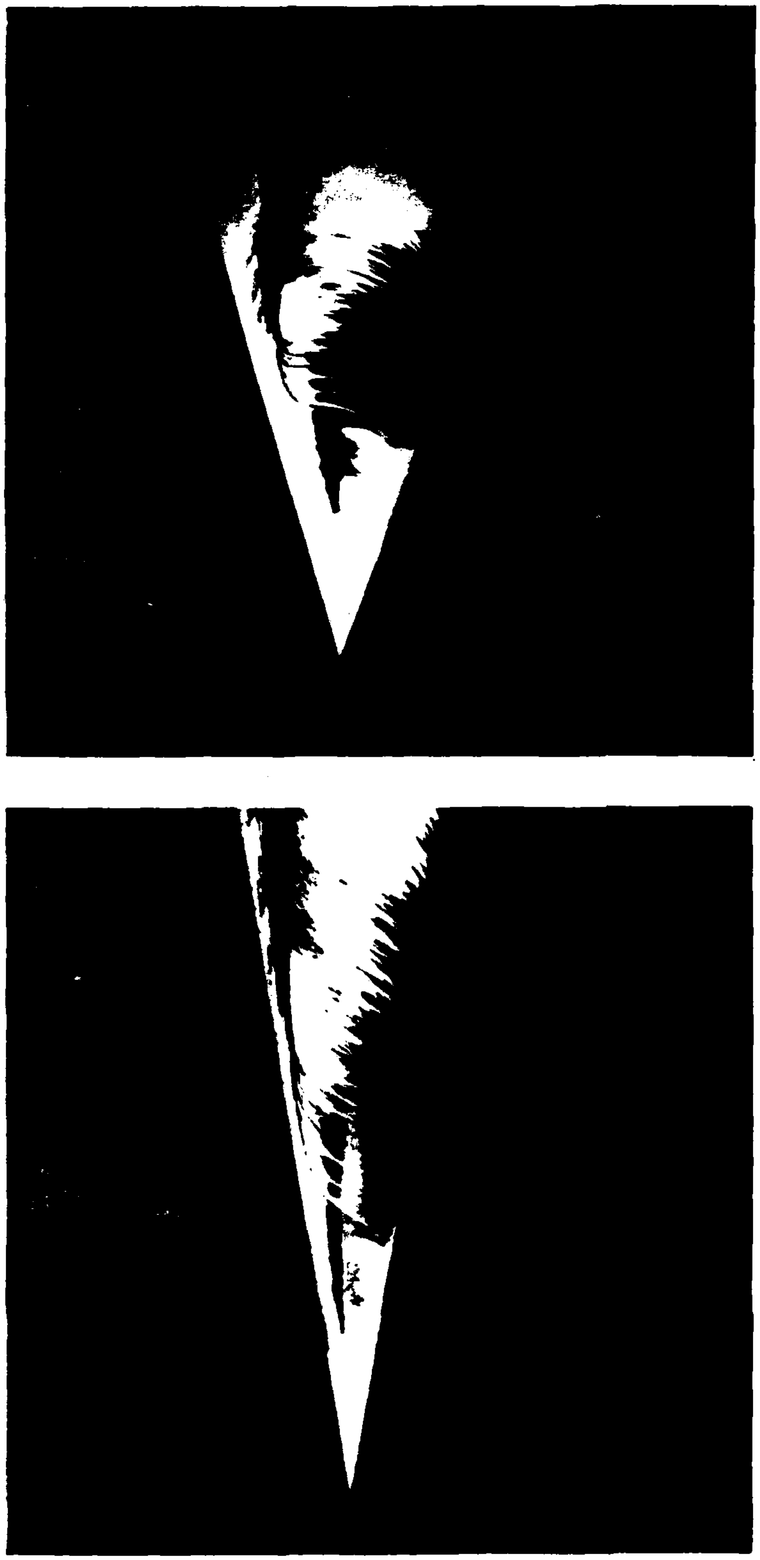
Reports quoted are not necessarily available to members of the public or to commercial organisations.

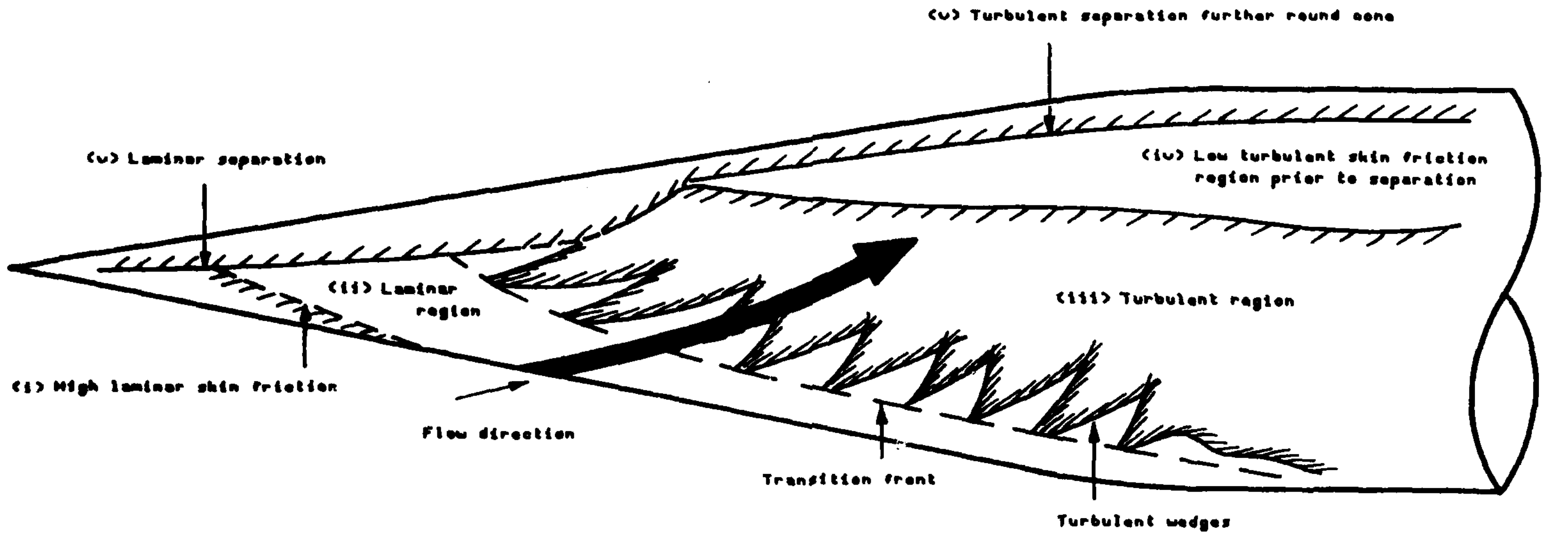
$\delta = 10^\circ$, $M = 0{\cdot}2$, 2 Atmospheres, $\alpha = 20^\circ$

Fig 1a China clay flow pattern on slender body nose



$\delta = 10^\circ$, $M = 0{\cdot}2$, 2 Atmospheres , $\alpha = 30^\circ$

Fig 1b China clay flow pattern on slender body nose



$\delta = 10^\circ$, $M = 0.2$, 2 Atmospheres, $\alpha = 30^\circ$

Fig 2 Diagram of flow pattern obtained with china clay technique

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